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ATTENUATION OF LASER RADIATION IN THE ATMOSPHERE

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ATTENUATION OF LASER RADIATION IN THE ATMOSPHERE

Yu. P. Safronov, Ya. A. Sukhanov, V. A. Poluarshinov
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ABSTRACT: The possibility of using lasers for various communication, location and tracking systems is noted; however, it is also noted that the spectral transparency of the atmosphere at various zenith angles becomes important in such cases.

Attention is called to the fact that ruby laser radiation is multimodal; the spectral range covered being about 0.6 Å, with a mean spacing between modes of about 0.035 Å. The helium-neon laser is closer to being monochromatic; variations are within the resolving power of the instrument, being less than 0.017 Å.

Atmospheric transmission at various zenith angles was measured by recording transmission of solar radiation of appropriate wavelengths. The apparatus used and the underlying theory are discussed briefly.

From this work, the following conclusions were reached:
1) for zenith angles of about 34°, the transmission of the whole atmosphere for ruby laser radiation is not less than 0.8; for the helium-neon laser at angles up to 73°, the transmission coefficient is 0.6;
2) the possibility of interference by some absorption bands of atmospheric gases is present, especially if the active body in the laser source becomes warmed;
3) the transmission of the atmosphere in the regions of intense absorption bands is 0.6 to 0.7 for the ruby laser; and 0.5 to 0.6 for the helium-neon laser.

In recent years the use of lasers has been contemplated in communication, /450* location, and tracking systems—particularly in "Earth-Cosmos" and "Cosmos--Earth" systems. Since 1965, experiments have been conducted in the U. S. A. on carrying out location of Explorer type satellites by use of a ruby laser [1].

Performing such a type of experiment unavoidably requires consideration of the spectral transparency of the atmosphere in the vertical direction under various zenith angles.

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*Numbers in the margin indicate pagination in the foreign text.

A study of the radiation spectrum of a "Razdan" type ruby laser and of a type "LG-55" helium-neon gas laser, using an ASP-20 horizontal solar diffraction spectrograph [2] has shown [3] that the radiation of a "Razdan" type ruby laser is multimodal. The number of modes attains 17 in individual pulses. All of the modes fall into the wavelength range $\Delta\lambda \approx 0.6$ Å. The mean spacing between modes is approximately equal to 0.035 Å.

Experiments performed on the same experimental set-up showed that the radiation of a helium-neon laser with respect to spectrum falls within the resolving capacity of the spectrograph; that is, the non-monochromaticity of this laser is less than 0.017 Å.

Simultaneous recording of the solar spectrum and the laser radiation has made it possible, from the lines with a definite wavelength which are available in the catalog, to determine the wavelength of the radiation from the LG-55 helium-neon laser, which proved to be equal to 6,328.38 ± 0.03 Å; that is, it differs from the accepted figure (6,328 Å) by no more than 0.5 Å. Thus, for the ruby laser, the spectrum band amounts to 0.6 Å; but for the helium-neon laser, to less than 0.017 Å.

To calculate the attenuation of laser radiation by the atmosphere, it is necessary to know the fine structure of the transmission spectrum of the atmosphere in the radiation region of these lasers.

Experiments on determining the fine structure of spectral transparency of the atmosphere were carried out under mountain-top conditions at a height of about 2,000 meters above sea level, on clear days, at a meteorological visibility range of not less than 30 kilometers. The experimental method reduces to recording the radiation spectrum of a part of the solar disk close to its center, the radiation having passed through the thickness of the atmosphere at various zenith angles. As the spectral instrument we used an ASP-20 solar spectrograph. This spectrograph permits carrying out spectral studies in the wavelength range from 3,000 to 11,000 Å with a resolving power in the red region of the spectrum of about 0.017 Å. As the scattering element we used a diffraction grating with a number of rulings per mm equal to 600. /451
The focal length of the collimator mirror was 6,966 mm [2].

The recording of the solar spectrum in the wavelength region of ruby laser radiation was performed on 20 May 1967, from 0600 to 1700 hours, for zenith angles from 78 to 34°.

A specimen of the solar radiation spectrogram with a spectrum range from 6,939 to 6,950 Å is shown in Figure 1. On the abscissa are plotted wavelengths in Å; on the ordinate, signal intensity in relative units. Intensive absorption bands of the terrestrial and solar atmospheres are visible on the spectrogram. The main absorption bands are associated with the presence of oxygen and water vapor molecules in the terrestrial atmosphere. Identification of these bands with tables of the spectra of chemical elements [4] shows that band h belongs to iron, which permits one to state that this band is of solar origin. The remaining bands are of terrestrial origin, since the ratio of the intensity magnitude in these bands to the intensity in "transparency windows" falls off with increase in zenith angle; that is, it depends on the mass of absorbing elements, while the relative intensity in the radiation band for iron remains constant for all angles.

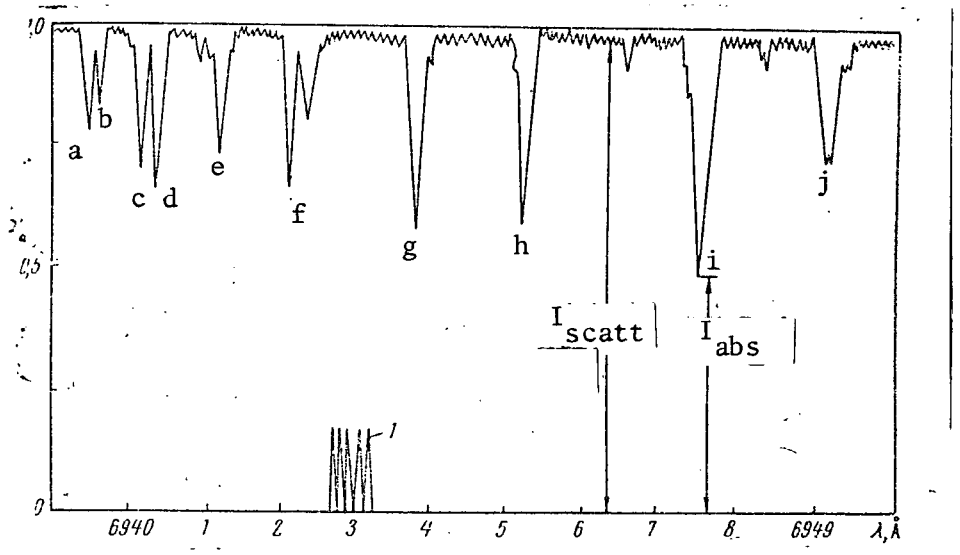

Figure 1. Sample of Spectrogram of Solar Radiation in the Spectrum Range 6,939 to 6,950 Å. 1, Indicates position of ruby laser radiation pulse.

Treatment of the spectrograms with the objective of obtaining quantitative characteristics of atmospheric transmission, both in "transparency windows," where attenuation of radiation takes place due to scattering on gas molecules and aerosols, and also in absorption bands of atmospheric gases, was carried out by the following method.

In "transparency windows" in the 6,943 Å region, the value of the transmission coefficient on a clear day in the vertical direction is 0.9 [5]. Attenuation of radiation due to scattering obeys well the Bouguer law:

$$\tau_\lambda = e^{-\beta m}, \qquad (1)$$

where τ_λ is the spectral transmission coefficient; β is the scattering coefficient; and m is the reduced mass of the scattering elements (molecules and aerosols). The reduced mass of the scattering elements as a function of zenith angle (z) has the form [5] /452

$$m = \frac{m_0}{\cos z + 0{,}025 e^{-11\cos z}}, \qquad (2)$$

where m_0 is the reduced mass of the scattering elements in the vertical direction.

Thus, the transmission coefficient for any zenith angle is presented in the following form:

$$\tau_{\lambda z} = 0{,}9^{\frac{1}{\cos z + 0{,}025 e^{-11\cos z}}} \qquad (3)$$

In Figure 2 we give, as a graph, the dependence of transmission in "transparency windows" in the 6,943 Å region, as calculated by formula (3), on zenith angle, from 78 to 34° (upper curve).

Transmission values in the absorption bands of atmospheric gases are determined by treating the experimental measurements as follows. The radiation intensity in "transparency windows," I_{scatt} (see Figure 1), is proportional to

the transmission in transmission bands ("transparency window"), but the magnitude of the intensity of I_{abs} is proportional to the transmission in absorption bands, $\tau_{\lambda\ abs}$. From these proportionalities, the transmission in absorption bands can be determined by the simple relationship

$$\tau_{\lambda\ abs} = \frac{I_{abs} \cdot \tau_{\lambda\ scatt}}{I_{scatt}} . \qquad (4)$$

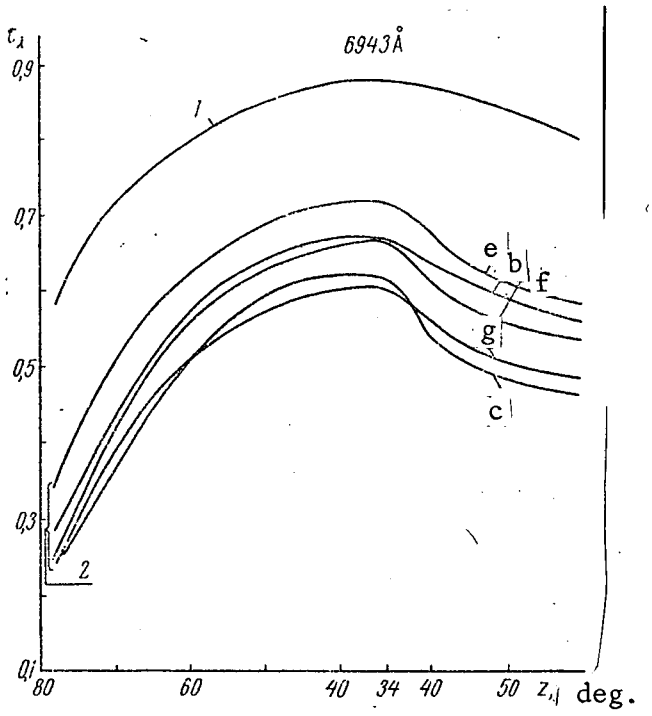

Figure 2. Transmission in "Transparency Windows" (1) and in Atmospheric Absorption Bands (2) in the Wavelength Region of Ruby Laser Radiation.

Values of $\tau_{\lambda\ abs}$ calculated for some absorption bands as a function of zenith angle are given in the form of graphs in Figure 2 (Curves e, b, f, g and c). A certain decrease in transmission after midday can apparently be explained by an increase in water vapor concentration in the atmosphere. /453

Additional experiments on recording the radiation spectrum of the solar disk in the radiation region of the helium-neon laser (6,328 Å) were performed under winter conditions (20 January 1967), therefore transmission spectrograms in this range were obtained only for large values of the zenith angles (89 to 73°). A specimen of the transmission spectrogram of the atmosphere in the range 6,323 to 6,331 Å is shown in Figure 3.

Values of spectral transmission in "transparency windows" and in absorption bands as a function of zenith angle, calculated by the method outlined above, are shown in Figure 4. In the calculations it was assumed that the transmission in the vertical direction in the 6,328 Å region has a value of 0.87 [5]. /454

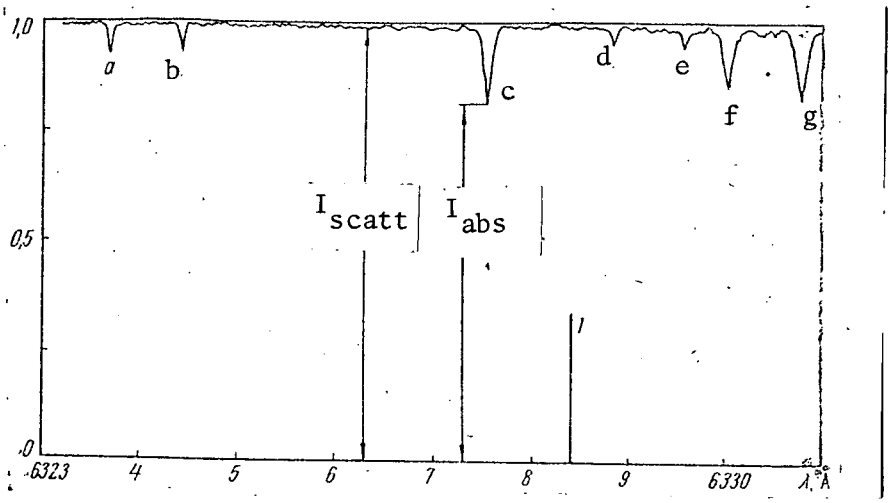

Figure 3. Sample of Radiation Spectrogram of the Sun in the Spectral Range 6,323 to 6,331 Å. 1, Marks the position of helium-neon laser radiation.

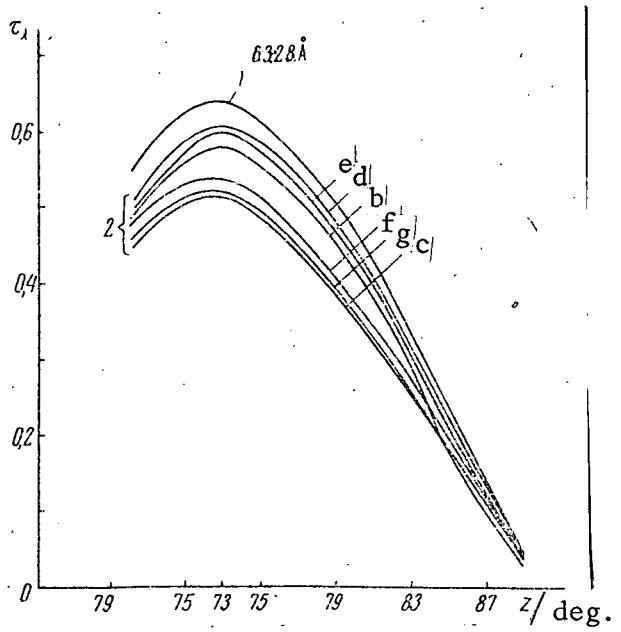

Figure 4. Transmission in "Transparency Windows" (1) and in Absorption Bands of Atmosphere in Wavelength Region of Helium--Neon Laser Radiation.

On the basis of the experimental studies and the calculations performed for attenuation of laser radiation in the atmosphere, the following conclusions can be drawn:

1) the transmission of the whole thickness of the atmosphere for ruby laser radiation (zenith angles of about 34°) has a value of not less than 0.8; but for the helium--neon laser, τ_λ = 0.6 (zenith angles up to 73°);

2) in the radiation range of the ruby laser or the helium--neon laser there are intense absorption bands of atmospheric gases; due to the change in spectral composition of the laser radiation caused by warming of

the active body [6], its radiation may be shifted with respect to spectrum, and in individual cases may coincide with these bands;

3) the transmission of the atmosphere in the intense absorption bands is as follows: for the ruby laser, τ_λ = 0.6 to 0.7 ($z \approx 34°$) and τ_λ = 0.5 to 0.6 for the helium-neon laser ($z \approx 73°$).

In conclusion we note that the results obtained must be considered as appraisal values, since the measurements were performed under mountain-top conditions where the number of absorbing elements in the beam path was not checked.

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